STAFF SUMMARY SHEET

	TO	ACTION	SIGNATURE (Surname), GRADE AND DATE		TO	ACTION	SIGNATURE (Surname), GRADE AND DATE
1	DFMI Dept Head	Approve	LtCol 7Nov2014	6			
2	DFER	Review	Soltz, AD22, 13 Nov 14 (*) needs Disclaimer	7			
3	DFMI	Action		8			
4				9			
5				10			

SURNAME OF ACTION OFFICER AND GRADE	SYMBOL	PHONE	TYPIST'S INITIALS	SUSPENSE DATE
Dr Talbot, AD-24	DFMI	333-9425	bt	

SUBJECT	DATE
Clearance of Material for Public Release USAFA-DF-PA-492	20141107

SUMMARY

1. PURPOSE: To provide security and policy review of the attached documents prior to public release.

2. BACKGROUND: Lt Col Michael Fowler, Assistant Professor, DFMI has written an article for submission to a military related journal, which will also be presented at the International Security Studies Section Conference at UT-Austin on 16 November.

Abstract: Lt Col Fowler's paper discusses the Future of Unmanned Aeriel Vehicles (or Drones) from a commercial, technical and military applications perspective. There are no direct statements making any judgments about Air Force or DOD policy, and thus, there should be no objections regarding public release of Lt Col Fowler's views.

Note that a disclaimer is included in the document, which states the following: "the views expressed in this article are those of the author and not necessarily those of the US Air Force Academy, the US Air Force, the Department of Defense, or the US government."

Release Information: Lt Col Fowler will present the article on 16 November 2014 at the ISSS meeting in Austin, and subsequenly may submit it to a military intelligence journal for publication, date and status TBD.

Recommended Distribution Statement: Distribution A, Approved for public release, distribution unlimited.

3. RECOMMENDATION: Sign Approve/Review blocks above indicating document is suitable for public release. Suitibility is based solely on the document being unclassified, not jeapordizing DOD interests, nor inaccurately portraying official policy.

B Talbot

Brent J. Talbot, PhD
Professor and Chief, Research Branch
Department of Military and Strategic Studies

The Future of Unmanned Aerial Vehicles

Michael Fowler, US Air Force Academy

For presentation to the International Security Studies Section Conference (ISSS/ISAC),

University of Texas, Austin, 15 November 2014

The views expressed in this article are those of the author and not necessarily those of the US Air Force Academy, the US Air Force, the Department of Defense, or the US government.

In February 2014, I attended a conference at the pentagon that brought together academics, defense contractors, and military practioners to discuss the future of small RPAs. Many of the attendees had an untempered enthusiasm for the future of RPAs. On the commercial side, their thoughts paralleled Lev Grossman's predictions for RPAs: "Police departments will use them to study crime scenes. Farmers will use them to watch their fields. Builders will use them to survey construction sites. Hollywood will use them to make movies."[1] From the military perspective, miniature UAVs would be used to "swarm" the enemy's air defense system.[2] These predictions largely focus on technological early adopters who will use RPAs simply because they exist and are economically feasible. These arguments are based on the presumptive logic that because a technology is (or will be) developed and could fulfill a function, it will be used for that function. This article uses innovation theory to critically analyze the likely future of UAVs using a framework of expected benefits and costs of adoption.[3]

The historical record shows numerous great technologies that were commercial failures. Products such as the Betamax video cassette recorder (1980s) and Iridium phones represent items that were technologically superior to alternatives and yet financial failures because they were not widely adopted. In 1964, Bell Systems invented the PicturePhone. An early version of video chat over your landline phone, it was a dismal failure. Total sales of a product is driven by cost and consumer demand. While the costs of UAVs continue to drop due to advances in miniaturization and nanotechnology, estimating demand is a challenge since many UAV activities can be accomplished by other means.

Most technologies enjoy the benefit of consumers known as innovators and early adopters who are venturesome and have a higher risk tolerance for expensive and not fully proven technology.[4] Grossman predicts that $50 and a smart phone will buy you a complete UAV system; low cost for a products based upon proven technology should lead to widespread

---

[1] Lev Grossman, "Drone Home," *Time*, Feb 11, 2013.
[2] For example, Paul Scharre, "Robotics on the Battlefield Part II: the Coming Swarm," *Center for a New American Security*, October 2014.
[3] Everett Rogers, *Diffusion of Innovations 5th ed.* (New York: Free Press, 2003), 233.
[4] Rogers, 282-283.

proliferation of small, line of sight UAVs. Current DoD policy largely restricts military UAV innovators to the Research and Development community. But as prices come down, early adoption could theoretically occur at the unit level since small purchases (e.g., under $2,500) are permitted with minimal bureaucratic approval processes.

However, this widespread adoption assumption is based upon a cost model that includes only the cost to purchase to the unit. While this may be a suitable cost model for the hobbyist, it is not sufficient for corporate or military operations since it does not account for related overhead and operating costs. The inevitable commercial UAV accident will eventually lead to workplace safety concerns and increased premiums for workplace insurance and worker's compensation. Technology adaptation typically drives requirements for new corporate policies, training, logistics (fuel and spare parts), maintenance, scheduling, supervision, and facilities (for storage). If the UAV is replacing a helicopter or other type of manned aircraft, then the change in overhead costs in minimized. But, if the UAV is replacing a function currently performed by personnel on the ground, the overhead costs could become a serious obstacle to technological adoption.

Similar to the corporate world, when the US military adopts a major new technology, there are cost implications, both monetary and man-hours, across the spectrum of DOTMLPF (Doctrine, Organization, Training, Management, Logistics, Personnel, and Facilities). In the zero-sum budget world of the Department of Defense (DoD), adoption of new technology involves additional risk because the cost must be offset by another program. Unlike the corporate world, the military cannot offset the additional costs of the technology adoption by using the new tool to create a new revenue stream. Therefore, increasing costs are scrutinized because the zero-growth budget requires the identification of cost offsets, a difficult and often politically charged process. To put the potential benefits and costs of future UAVs into context, this article will first review the existing benefits and costs of UAVs relative to manned aircraft.

The contemporary UAV performs a variety of combat missions that tend to fall into one of two categories: support to ground forces or participation in the joint targeting process. UAV support to ground forces includes Close Air Support (CAS) for troops in contact, route reconnaissance, security over-watch, communications relay, and support for counter-battery fire. For targeting, UAVs are especially useful for target development, target clearance (to minimize collateral damage), and Battle Damage Assessment (BDA). However, none of these missions are unique to UAVs. Each can be accomplished by manned aircraft. In fact, even the UAVs dual-role as ISR and attack platform is also available in a manned aircraft version. Yet, demand from the combatant commanders for UAVs far outstrips supply.

Current UAVs have a variety of competitive advantages that make them more desirable for certain missions or operations than their manned aircraft counterparts. UAVs have a smaller logistics footprint. UAVs can operate out of austere locations or navy destroyers. Smaller, less capable UAVs can be carried in a backpack. Compared to most other ISR platforms, UAVs are

less observable, and have superior on-station time. Compared to strike aircraft, UAVs provide superior target discrimination, less potential for collateral damage, and reduced risk to the aircrew.

Of course, current versions of UAVs have a variety of disadvantages. They tend to have lower thresholds for adverse weather, a smaller field of view, and lack defensive countermeasures. And while an MQ-9 is significantly cheaper than an F-35, the cost advantage per flight hour compare to non-stealth manned aircraft is negligible from a system perspective.

From an incremental innovation standpoint, the most likely near-term advances in UAVs will begin by decreasing the disadvantages and increasing the advantages. Considering that the US Air Force is the primary provider of UAVs to the joint commander, this study will approach the costs and benefits of UAV innovation through an Air Force core missions framework. Therefore, this study will evaluate the future potential of UAVs to conduct air superiority; Intelligence, Surveillance, and Reconnaissance (ISR); Rapid Global Mobility; Global Strike; and Command and Control (C2).

Today's UAV plays essentially no role in air superiority. UAV designs would need to make significant upgrades in radar, weapons, and defensive countermeasures. In order to dogfight, major improvements in pilot field-of-view would be necessary. Unfortunately, all of these upgrades add weight and bandwidth requirements. Theoretically, savings could be attained by making the UAV semi or fully autonomous. Additional field of view would be unnecessary. And, if the UAV could be made inexpensively, perhaps the defensive countermeasures would become an unnecessary expense.

Near term adoption of fully autonomous UAVs for lethal combat missions is unlikely in the near term due to concerns over ethics, the quality of target discrimination, and Air Force cultural resistance. Of all lethal missions, air-to-air missions are the most plausible for a UAV since target discrimination in a combat zone is less complex than an air-to-ground mission. Air to air target discrimination is technically feasible.[5] Even so, to negate ethical and target discrimination concerts, the actual decision to destroy a target could be reserved for a command center such as a Combined Air Operations Center (CAOC) or Airborne Warning and Control System (AWACS). The autonomous UAV would simply be responsible for executing the attack mission giving to it by the command center. From a target discrimination perspective, this is not significantly different than a fighter firing a long range missile beyond visual range when directed by AWACS that the target is hostile.

However, for many UAV missions, greater autonomy will initially focus upon flight operations. Defense company are working on UAVs with multi-day loiter times. These exponential increases in loiter times will require an increasing reliance on semi-autonomous navigation. However, automating the mission and the sensor operator will be a far more difficult challenge. Semi-autonomous flight operations will enable a single pilot to control multiple aircraft. UAVs spend a considerable amount of time transiting to/from and orbiting over the

[5] See Michael Byrnes, "Nightfall: Machine Autonomy in Air to Air Combat," *Air and Space Power Journal*, May-June 2014, 48-75, available at: http://www.airpower.maxwell.af.mil/digital/pdf/articles/2014-May-Jun/F-Byrnes.pdf

target. These simple maneuvers can easily be executed by current auto-pilot technology. Of course, such an implementation would limit the flexibility and responsiveness of the UAVs.

Along with additional loiter times, new UAVs will carry multiple sensors increasing the load for sensor operators. One DARPA project claims to use over 300 mini-sensors to create 65 video feeds. While this is an incredible increase in capability, these developments will entail significant costs in manpower and bandwidth. Adoption of this technology will naturally lead to additional emphasis on automated sensor operations. A semi-automated UAV could certainly conduct a significant portion of pre-planned and ad-hoc ISR collection including still imagery photos, communications intelligence, electronic intelligence, and some specialized measuring and signals intelligence. Programming a UAV to track mobile targets using full motion video would certainly be more complex, but is in the realm of the possible.

Arguably, the proliferation of small, inexpensive UAVs could lead to the adoption of UAVs to do other functions such as tactical weather forecasting, base security, and NBC detection. The downside of these improvements such as additional loiter time, sensors, and aircraft is data overload. On the technology side, improved communications will be necessary to handle the additional bandwidth requirements. On the personnel side, semi-automated intelligence processing, data storage, and video search capabilities will be necessary for the intelligence community which is already overwhelmed with data from existing sources. The military R&D community continues to explore methods to automate the intelligence fusion process. While automated systems helped with data integration and visualization, the heavy lifting of intelligence fusion is still dependent upon grey matter.

Meanwhile, this proliferation of many UAVs presents an opportunity to create extended networks. UAVs could act as sensor and relay nodes for air-to-air surveillance, air-to-ground surveillance, electronic surveillance, and communications.

To make an adoption of a massive fleet of small UAVs feasible, new UAVs will need to be logistics-conscious. The concept of a single pilot flying multiple UAVs is one method to reduce the logistical burden. More importantly, the UAVs will need to reduce their footprint downrange. Perhaps this will involve maintenance robots using a three-dimensional printer for spare parts.

On the other hand, UAVs may be part of the logistics solution. In Afghanistan, the Marine Corps used an experimental UAV helicopter to transport goods in areas that involved high risk for helicopter take off and landings. Using UAVs to haul cargo is a relatively simple venture as long as the aircraft can be made reliable enough to minimize risk of losing the cargo. Using a UAV to transport personnel would likely only follow after an extended proven safety record of cargo transport. A proven safety record would also likely lead to adoption for UAVs for air-to-air refueling. UAVs could also take on higher risk transport missions such as personnel recovery and firefighting.

On the opposite extreme, fully automated air-to-ground strike UAVs is a far less likely innovation, at least for US forces. Of course, the United States area uses fully automated weapons against fixed targets or ships; we call them cruise missiles. But, cruise missiles are not good at target discrimination. Arguably, the technology already exists to make lots of strike UAVs without regard for target discrimination. But, this is not logical. If a regime has little concern for collateral damage, international opinion, and domestic opinion, then it seems

unlikely that the UAV would be the weapon of choice. It is counterintuitive that such a regime would spend the resources necessary to reduce risk to the pilot. But, if it does matter, significant effort will need to be made to enable target discrimination logic that is typically derived from subjective judgments.

For most UAV strike targets, the current process in the Air Operations Center involves a detailed cross-check between the Battlefield Control Detachment (to deconflict with friendly ground forces), the Special Operations Liaison Element (to deconflict with Special Operations Forces), lawyer (to ensure the target meets Law of Armed Conflict requirements), targeteer (estimates anticipated collateral damage, matches preferred weapons to target type & desired effects), airspace deconfliction (clear path from aircraft to target), and the offensive duty officer (assign the target to an aircraft). Much of this coordination involves subjective judgments that will be difficult to automate. Alternatively, it may be possible to partially automate the process, flagging issues that require subjective interpretation by a human operator.

In the interim, a more likely innovation would be an Ender's Game style virtual control center. In this case, the UAV follows pre-programmed logic for specific tasks but still involves a human-in-the-loop to provide subjective decision making. This type of innovation would be a useful method to take advantage of the decreasing cost of UAVs. Lots of UAVs controlled from a minimal number of command centers would "bring mass back to the fight" in an era of dramatically rising aircraft per unit costs.[6] The increasing costs and production times to create survivable manned aircraft increases the comparative cost advantage of RPAs.

If UAVs were cheap enough, it would enable the creation of mini-RPA "swarms." Advanced software algorithms already exist which will enable groups of UAVs to fly cooperatively. Swarm theory is reminiscent of classic airpower theorist's Gulio Douhet argument that aerial defense is inefficient due to the dispersion of resources to cover the variety of potential routes and targets.[7] A swarm "complicates an adversary's targeting problem and allows graceful degradation of combat power as assets are attrited."[8] The development of a swarm provides lots of possibilities for offensive use. An inexpensive UAV kamikaze would be useful for nearly any type of lethal mission. Swarms would also present a complex challenge for adversary air defenses simply due to overwhelming numbers or act as cheap decoys designed to absorb surface to air missiles.[9]

A swarm is one method to improve UAV access in an advanced air defense environment. While the development of defensive countermeasures such as a jamming pod and a flare dispenser are plausible, the addition of the extra weight and expense runs counter to the inherent

---

[6] Paul Scharre, "Robotics on the Battlefield Part II: the Coming Swarm," *Center for a New American Security*, October 2014, 6.

[7] Giulio Douhet, *The Command of the Air*, trans. Dino Ferrari, reprint ed. (Washington: Office of Air Force History, 1983), 15-19.

[8] Scharre, 6.

[9] For history of UAVs as decoys, see Thomas P. Ehrhard, *Air Force UAVs: the Secret History*, (Arlington, VA: Mitchell Institute for Airpower Studies, July 2010), 25.

cost savings of using UAVs. Another alternative to lots of cheap aircraft is the further development of stealth UAVs. While the technology is already proven, reliance upon high price UAVs will leave the fleet lacking in sufficient quantity to meet operational demands. There just will not be enough to go around.

Alternative methods of stealth are evolving in the field of miniaturization. The invention of nano UAVs opened a new path for low observability without expensive radar-evading technology. To get the full functionality of nano UAVs, they need to be capable of beyond line of sight (BLOS) operations and operate inside buildings. Unfortunately, this tends to require increased power for range and communications that grow the UAV beyond the nano size. An alternative to BLOS is dropping the nano UAVs from a mother ship such as a C-17. Unfortunately, without a stealth mother ship the concept is limited to operations where the adversary has limited air defense capabilities.

Advances in nano-technology also birthed the feasibility of bio-drones. When a UC Boulder brought the concept up at a recent conference, the inherent advantages were not obvious. Considering that animal rights groups convinced the US Army to stop using pigs to teach combat trauma first aid after, it seemed unlikely that the military would turn animals into UAVs. Since the technology requires some type of brain control, the cruelty involved seems unlikely to meet the military necessity threshold.

But, this is some room for innovation here. A dolphin is more agile and faster than any remote control submarine. The Navy uses dolphins to help detect underwater booby traps and mines. Putting a Go-Pro-like camera on one of these dolphins is a simple solution. However, this lesson does not seem to transfer to the ground or air domain. There seems to be no advantage to putting a small camera on a trained pigeon. Regardless, implementing some type of brain control of a dolphin or bird seems to cross some sort of ethical red line.

Interestingly, humans seem to have less empathy for insects. A company called Backyard Brain developed RoboRoach which uses neuroscience to attempt to control the movements of a live roach. Insect-drones could be the ultimate clandestine ISR, becoming the proverbial "fly on the wall" to watch and listen to the adversary. But, the fact that an insect can be controlled by remote control does not necessarily make it a good candidate for a UAV. The major technological challenge will be solving the power problem for the mini camera and the two way communications packages that will enable the roach to go BLOS. Plus, the insect will still need to eat and rest.

To mitigate the challenges of biological functions, technology is already starting to create man-made insect UAVs. Harvard's Monolithic Bee and Robugtix's Spider are but two early examples that suggest that the development of a realistic looking robot insect can be used as a UAV. Plus, a robot insect may be able to overcome the power limitation. Ideally, a robot insect can harvest energy from the environment such as solar or wind. For high power needs, the robot can plug into power lines or electrical outlets.

One drawback to any nano UAS will be its survivability in an Electronic Warfare (EW) environment. Two key factors in EW are power and distance. The Nano UAS will have problems with both. It is designed to be extremely close to the adversary and far from the friendly communications node. Its small size will inherently limit its total power to transmit

clearly through enemy jamming. Even with advancements in technology, the Nano UAS is likely to be at a comparative disadvantage relative to the adversary's EW system. This suggests that Nano UAS will be most appropriate for environments in which there is a low threat of Electronic Attack. Unfortunately, this leads us back to expensive stealth as the most likely answer for an advanced air defense system.

As UAVs continue to proliferate, there will be increased demand to reduce the command and control burden of UAVs. A major effort underway in this arena is detect and avoid technology in order to help reduce the probability of a mid-air collision. While this technology will improve safety at congested military bases, it will also be a boon to help the Federal Aviation Administration's job to define rules to enable UAVs and manned aircraft to share the same airspace. One of the likely side effects of the military's research efforts on UAV detect and avoid technology will be increased domestic use of UAVs by law enforcement entities such as the Federal Bureau of Investigation, Border Patrol, Secret Service, Coast Guard and local law enforcement.

UAVs provide a significant advantage over ground and maritime patrols due to the increased field of view. While privacy concerns of spying on US citizens continue to make media headlines, UAVs are actually less of a privacy threat than manned aircraft. Compared to manned aircraft, UAVs have a "soda straw" field of view which limits their ability to view areas outside of the authorized target. Sensors analyst tend to be over-tasked, limiting their time to view the video while in transit. In a manned aircraft, the pilot is constantly viewing the surroundings to maintain situational awareness. Of course, not all manned aircraft have video recorders, but many do. If a pilot without a video recorder violates a citizen's privacy, there is no record of it. For UAV videos, overseers can monitor video feeds to audit employment and ensure they are following privacy policies.

The use of weapons on UAVs over the US seems unlikely. While there is significant potential for increasing adoption of UAVs by the Air National Guard for dual use for military operations (Title 10) and law enforcement (Title 12 or State status), the arming of these military aircraft to support domestic operations is not a logical conclusion. Most states already have the potential access to the fighter aircraft of their state Air National Guard. And yet, these aircraft are not used to bomb criminals.

Advances in technology present a multitude of options for innovation of UAVs for military operations. Yet, just because a UAV can do a function does not mean that it will be adopted for that function. Many of the advances in UAV technology require additional advances in power and miniaturization to make them fully function in an operational environment. Increases in automation are likely to enable the proliferation of more vehicles without requiring additional pilots. Fully automated UAVs though are likely to be limited to combat support roles, not the employment of lethal force. Or, at least, the decision to employ lethal force will not be delegated to the automated platform. While an automated UAV may employ lethal force, it will be at the direction of a manned command and control platform. Advancements in UAVs to survive in advanced air defense and electronic warfare environments face significant challenges.

But, new UAV technologies such as nano technology and neuroscience will thrive in the irregular warfare environment.